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CENTRE FOR EXPLORATION TARGETING AND ANALYTIC SIGNAL TECHNIQUES AS TOOLS FOR INTERPRETATION OF AEROMAGNETIC DATA: EMPHASIS ON PARTS OF MID-NIGER BASIN, NIGERIA

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ABSTRACT
Ten aeromagnetic data sheets (each measuring about 55.74km^2) covering some parts of Mid-Niger Basin, Nigeria and situated within latitude 8^{0}00'N - 10^{0}00'N and longitude 4^{0}30'E - 7^{0}00'E were acquired from the Geological Survey Agency of Nigeria and interpreted, using Oasis Montaj software. The data was digitized and assembled to produce a joint aeromagnetic data file for the area. The data was first reduced to pole and then subjected to CET grid analysis and analytical signal methods. The result of application of the CET phase symmetry grid analysis to the Total Magnetic Field Intensity data revealed the line-like regions of discontinuity and lineaments within the study area. The result of the amplitude domain analytic signal shows high amplitudes, ranging from 0.344 to 0.218 cycles which might be due to outcrops of magnetic rocks while intermediate structures have amplitudes ranging from 0.218 to 0.096 cycles could be areas of shallow intrusions of magnetic rocks into the sedimentary basin. The regions with the lowest amplitudes ranging from 0.096 – 0.064 cycles connote regions of deeper magnetic rocks at the basement depicting the trending of the basin in a NW-SE direction. The line-like regions and lineament features as well as the low amplitude regions could serve as migration and depositional environments for minerals and hydrocarbon accumulation respectively.

Keywords: Phase symmetry, Analytic Signal, Amplitudes, lineaments

INTRODUCTION
Nigeria is blessed with enormous mineral resources that are fairly distributed across the country that if explored and exploited could boost the country's economy fortunes. The mainstay of the country's economy has been the depleting petroleum reservoirs as there is the possibility that the existing quantity may be exhausted in the nearest future. There is, therefore, the need to explore for more reserves of hydrocarbon to augment the existing quantity and to develop the natural minerals as a credible alternative. Accordingly, a proper geophysical prospecting which would be aimed at ascertaining the presence of potential areas of hydrocarbon accumulation and mineral deposits is of paramount interest in this research.
Magnetic survey is one of the many geophysical survey techniques aimed at investigating subsurface structures on the basis of the anomalies in the earth's magnetic field. The variation in magnetic field intensity of rocks arises to the type of rocks, susceptibility, thickness of overburden and elevation, with susceptibility playing the key role. These anomalies could be of remnant or induced nature and could give a clue to the presence of certain magnetic features of economic interest.

The precision with which magnetic methods reveal anomalous regions in the Earth's subsurface prompted the use of the method in the interpretation of the total magnetic field intensity data over some parts of the Northern Mid-Niger Basin of Nigeria with a view to evaluating the lineament structures and regions of varying amplitudes which symbolize different depths within the study area.

The CET (Centre for Exploration Targeting) Grid Analysis extension for Oasis montaj consists of a number of tools that provide automated lineament detection of gridded data, which can be used for first-pass data processing. These tools provide a rapid unbiased workflow that reduces the time with which one can interpret gridded data. The method contains tools for texture analysis, phase analysis, and structure detection which are versatile algorithms useful for grid texture analysis, lineament detection, edge detection, and threshold detection. It provides a step-by-step trend detection menu which offers two different approaches to trend estimation: *Texture analysis-based image enhancement*, which is suitable for analyzing regions of subdued magnetic responses where texture analysis can first enhance the local data contrast; and *Discontinuity structure detection* which is useful in identifying linear discontinuities and edge detection.
The analytic signal method on the other hand, is useful in locating the edges of magnetic source bodies, particularly where remanence and /or low magnetic latitude complicate interpretation. The width of an anomaly gives an indication of the depth of the contact as long as the signal arising from a single contact can be identified. The method is often more useful at low magnetic latitudes as it is applied to data that has been reduced to pole. The method can as well be applied to data that has not been reduced to pole and still yield the desired result since the anomalies are usually properly shifted over top of the causative bodies

Among the geophysical works conducted in the basin using magnetic and other methods are: Ojo and Ajakaiye, (1989) who delineated the presence of a positive gravity residual centre in the basin and attributed this to the presence of a shallow metamorphic basement of high density and intermediate composition which they deduced was probably of schist; and negative anomalies which were ascribed to relatively great thicknesses of sediments; Ojo, (1990) who investigated a major east-west magnetic low whose deep seated structures dominated the southern part of the basin. Udensi, (2001) also identified the landward prolongation of St. Paul and Romanche fracture zones as lineaments passing through the northern and southern parts of Mid-Niger Basin. In the spectral determination of depths to magnetic rocks in the Mid-Niger Basin. Udensi and Osazuwa (2004) outlined the basin as being bounded by a system of linear faults. Udensi and Osazuwa, (2004) also used statistical analysis to estimate the average depth to basement of the basin to be 3.39km. Ofor *et al*., (2014) carried out a study of Pategi and Egbako areas of the lower Mid-Niger Basin and revealed two prominent layers; with average values of 0.59km and 3.1km. Megwara, and Udensi, (2014) also carried out structural analysis using aeromagnetic data over parts of southern Mid-Niger Basin and the surrounding basement rocks to highlight trend characteristics of magnetic lineaments.

Location and Geology of the Study Area

The basin is bordered in the NE and SW by the basement complex and merges with the Anambra and Sokoto basin to the SE and NW respectively. It is located between latitudes 7.30^0 N and 10. 00^{0}N; and longitude 4.00^{0}E and 7.00^{0}E (Obi, 2015). Figure 1 is the geology and location map of Nigeria showing the Mid-Niger Basin.

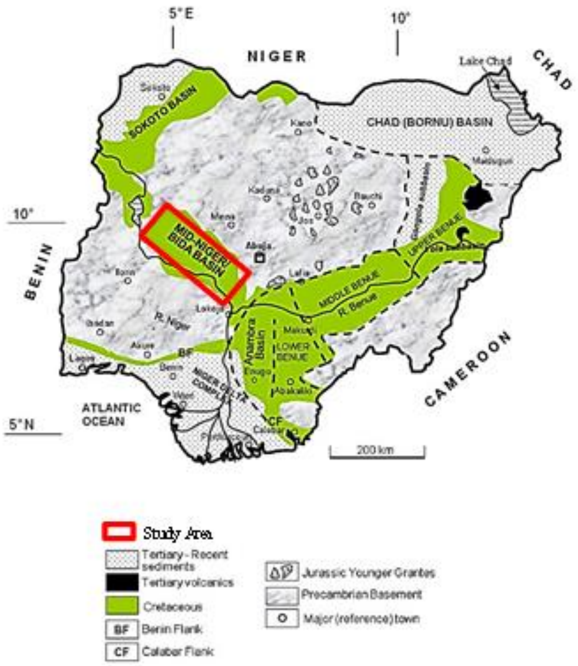

Figure 1: Geological map of Nigeria showing the Mid-Niger Basin (After Obaje, 2009)

The basin is divided into the Bida Sandstone and Lokoja formation which were produced during the Campanian, and the Sakpe, Enagi, Batati, Patti and Agbaja formations which were created during the Maastrichtian. The Bida Formation is divided into the Doko and Jima Members. Adeleye (1974) reported that the Doko Member is about 183m thick showing localized development of cross-stratification with the Jima Member being about 90m thick and predominantly sandy. The Doko Member, located 16km south of Bida is the basal unit and consists of 80m of massive and flat bedded arkoses and coarse to medium sandstone with breccia horizons (Olaniyan *et al.,* 2012). Adeleye (1989) and Obaje (2009) also viewed the member as having fairly to poorly sort and exposed pebbly, sub-arkoses and quartzose sandstones with granular to sub-granular grains which are thought to have been deposited in a braided alluvial fan setting. The sandstones of the Jima Member (Jima Sandstone subfacies), according to Adeleye (1989), are dominantly quartzose, non-arkosic and brownish. Thin intercalations of poorly sorted, hard, whitish, argillaceous sandstones are locally present in the lower parts of the Jima subfacies. The colours of the quartz grains are also similar to those of the underlying subfacies. Shiny, blackish ferruginous mineral, possibly goethite/haematite, form the cement and some weak to strong concentric growth shells are displayed.

The Sakpe Formation comprises mainly oolitic and pisolitic ironstones with sandy claystones locally, at the base, followed by dominantly oolitic ironstone which exhibits rapid facies changes across the basin at the top (Adeleye, 1973). The Enagi Formation as described by Obaje (2009), on the other hand, consists mainly of siltstones and correlates with the Patti Formation in the Lokoja sub-basin. Other subsidiary lithologies include sandstone-siltstone with some claystones. Fossil leaf impressions and rootlets have been found within the formation. The formation ranges in thickness between 30m and 60m. Mineral assemblage consists mainly of quartz, feldspars and clay. The Batati formation constitutes the uppermost units in the sedimentary sequence of the Mid-Niger Basin. It consists, according to Obaje *et al.* (2013), of argillaceous, oolitic and goethite ironstones with ferruginous claystone and siltstone intercalations and shaly beds which occur in minor proportions some of which have yielded near shore shallow marine to fresh water fauna. Figure 2 shows the stratigraphic successions of the basin.

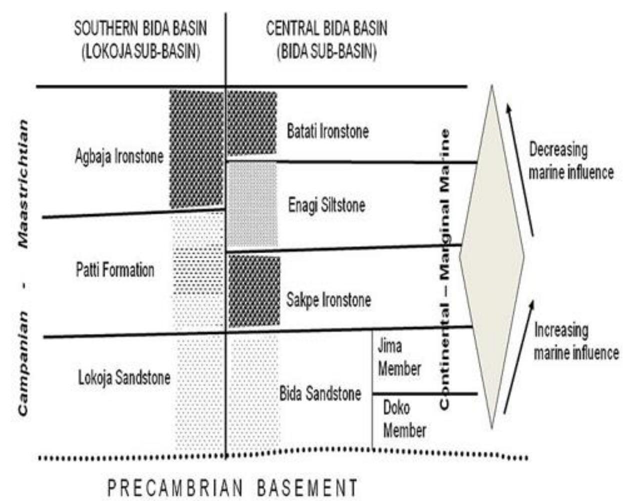

Figure 2. Stratigraphic successions in the Mid-Niger Basin (after Obaje, 2009)

The Lithologic units in Lokoja Formation according to Akande *et al*., (2005) consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones with the argillaceous units predominating in the central parts of the basin. The Agbaja Formation consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region.

MATERIALS AND METHODS

The IGRF corrected data (Figure 3) was acquired from Nigerian Geological Survey Agency, through the IBBU hydrocarbon Research Group, digitized and then reduced to pole using Oasis montaj software.

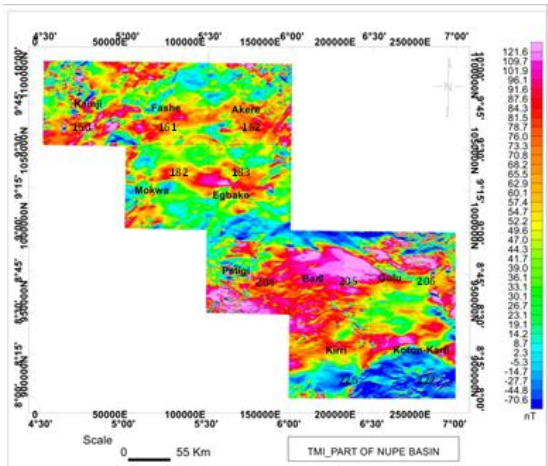

Figure 3: 2009 IGRF Corrected TMI data on sheets covering Parts of Mid-Niger Basin.

Magnetic anomalies usually have positive and negative peaks associated with them, thereby making it difficult to determination the exact location of causative body. The analytic signal method simplifies this scenario by using the derivatives of the magnetic field independent of the angles of strike, dip, inclination, declination and remanent magnetization (Debeglia and Corpel, 1997)

Nabighian (1974) developed the concept of two dimensional analytic signal also referred to as energy envelope of magnetic anomalies. Roest *et al.* (1992) showed that the amplitude of the three dimensional analytic signal at location (x, y) can be derived from the three orthogonal gradients of the total magnetic field using the equation:

$$|A(x,y,z)| = \left[\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2 + \left(\frac{dT}{dz}\right)^2\right]^{\frac{1}{2}} \qquad (1)$$

where $|A(x,y)|$ is the amplitude of the analytic signal at (*x , y, z*).
T is the observed magnetic field at (*x, y, z*).

The analytic signal anomaly over a two dimensional magnetic contact located at (x = 0) and at depth h is described according to Nabighian (1972) as:

$$|A(x,y)| = \alpha \frac{1}{(h^2+x^2)^{\frac{1}{2}}} \qquad (2)$$

The constant,

$$\alpha = 2M\sin(D)[1-\cos^2(I)\sin^2(A)] \qquad (3)$$

represents the amplitude factor and
h = the depth to the top of the contact
M = the strength of magnetization
D = the dip of the contact
I = the inclination of the magnetization vector
A = the direction of the magnetization vector

The analytic signal described by equation (2) is a bell shaped function in which all directional terms are contained in the amplitude factor α (MacLeod, *et al*., 1993). Here, only the amplitude of the analytic signal is affected by the vector components of the model. The shape of the analytic signal is dependent only on depth (MacLeod *et al.,* 1993). In a similar way, it can be shown that the analytic signal over a two dimensional magnetic dike can be described by the equation:

$$|A(x,y)| = \alpha \frac{1}{(h^2+x^2)} \qquad (4)$$

According to MacLeod *et al.* (1993), the use of a three dimensional presentation is to show how the amplitude of the analytic signal peaks over the edges of the model. The amplitude of the peaks is proportional to the magnetization at that edge as defined by the amplitude factor.

Reduction to Magnetic Pole (RTP)

Reduction to the pole (RTP) is a standard part of magnetic data processing method, especially for large-scale mapping. RTP operation can transform a magnetic anomaly caused by an arbitrary source into the anomaly that the same source would produce if it were located at the magnetic pole and magnetized by induction only. RTP also helps in interpretation of magnetic data by removing the influence of magnetic latitude on the anomalies.

Centre for Exploration Targeting (CET) Phase Symmetry Grid Analysis

CET Grid Analyses system examines the texture of an image to detect any laterally continuous line-like regions of discontinuity such as lineaments along ridges and edges as well as areas of structural complexity using standard deviation to locate deposit occurrence favorability. Since magnetic field data delineate geologic structures relatively well, the method is applied to the pole reduced data so that anomalies are shifted over their causative structures.

RESULTS AND DISCUSSION

Usually low magnetic anomalies in a sedimentary basin are associated with thick overburden while high magnetic anomalies are concomitant with shallow overburden, except where high values are associated with the presence of magnetic ores. The interpretation of the aeromagnetic data of some parts of Mid-Niger Basin has successfully delineated areas of high and low magnetic anomalies which were associated, in most cases, with thick and thin overburdens for low and high magnetic anomalies respectively. There were, however, some areas which showed high magnetic anomalies but were geologically identified with thick sedimentary overburdens. This could be attributed to the presence of magnetic minerals such as limonite, hematite, magnetite, siderite and chamosite which are of ironstones origin. Oasis Montaj software was used to reduce the total magnetic field intensity data to pole and the result is shown in Figure 4.

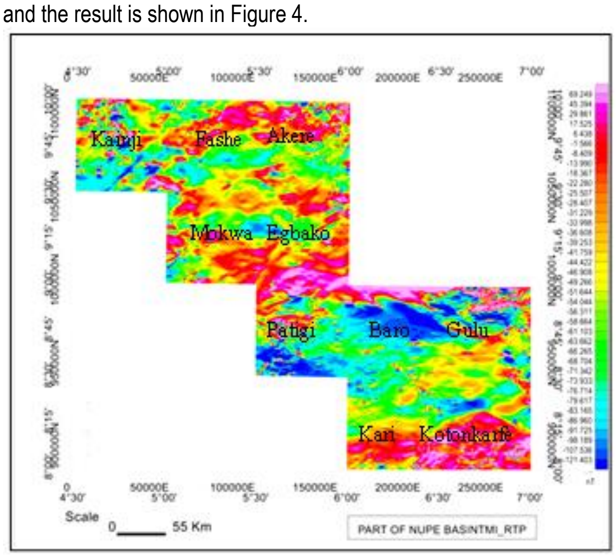

Figure 4: 2009 IGRF Corrected TMI data of Parts of Bida/Nupe Basin Reduced to Pole

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From the map, a negative broad and deep seated magnetic anomaly could be observed around areas bounded by latitudes $8^0 45'$ N - $9^0 00'$ N and longitudes $5^0 30'$ E - $6^0 50'$ E. This region is shown in blue colour on the RTP map and corresponds to areas around south of Patigi, Baro and north of Gulu. Sandwiching this region are broad and deep seated positive magnetic anomalies covering areas around latitudes $8^0 00'$ N to $8^0 15'$ N and longitudes $6^0 00'$ E to $7^0 00'$ E below and situated on magnetic sheets covering areas around the southern parts of Kotonkarfe and Kirri; and latitude $9^0 00'$ N to $9^0 30'$ N and longitude $5^0 15'$ E to $6^0 00'$ E above covering areas around the extreme north of Baro, Gulu and Patigi as well as southern Egbako. There are also some deep pockets of negative and positive anomalies scattered around the region which could be attributed to the nature of the region which is known to be dominated by sandstones and siltstones which are nonmagnetic, and ironstones which are magnetic in nature. The yellow bands represent the transition between these regions and clearly show the edges of the shapes of the anomalies.
Figure 5 shows the result of the application of the CET phase symmetry grid analysis to the TMI data which has revealed the line-like regions of discontinuity and lineaments within the study area as seen in Figure 5. From the Figure, it is obvious that the areas shown in blue colouration and representing areas with very low amplitudes are those due to deeper magnetic sources. This region is observed to follow a NW- SE trend which happens to coincide with the trending of the basin. The areas depicted by purple colour, on the other hand, are shallow depths arising, most likely, due to intrusions from the basement at different depths. These areas are observed predominantly in the vicinity of Kirri, Gulu north, southern parts of Kotonkarfe and Patigi as well as Kainji east and Akere west.

To obtain the analytic signal that shows the structures within the basin, computed x-, y- and z- derivatives were used in Oasis Montaj as input grids so that the amplitude is independent of the direction of magnetisation. The result of the amplitude domain analytic signal is shown in Figure 6 where areas in purple colour, signifying high amplitudes, ranging from 0.344 to 0.218 cycles, result due to outcrops of magnetic rocks while intermediate structures are represented in red colour which range from 0.218 to 0.096 cycles. These are areas which could be attributed to intrusions of magnetic basement into the sedimentary basin. The regions with the lowest amplitudes connote regions of deep basement which arise due to the magnetic basement at greater depths. This region has a range of amplitudes from 0.096 – 0.064 cycles and is shown in yellow and green colours and trending in the NW-SE direction.

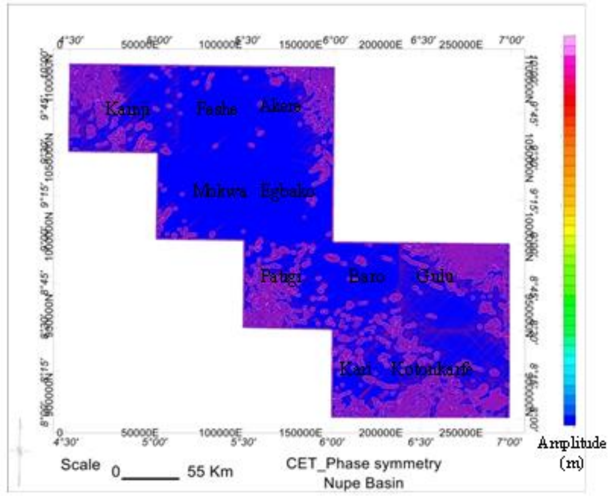

Figure 5: Phase Symmetry showing areas of discontinuity and lineaments

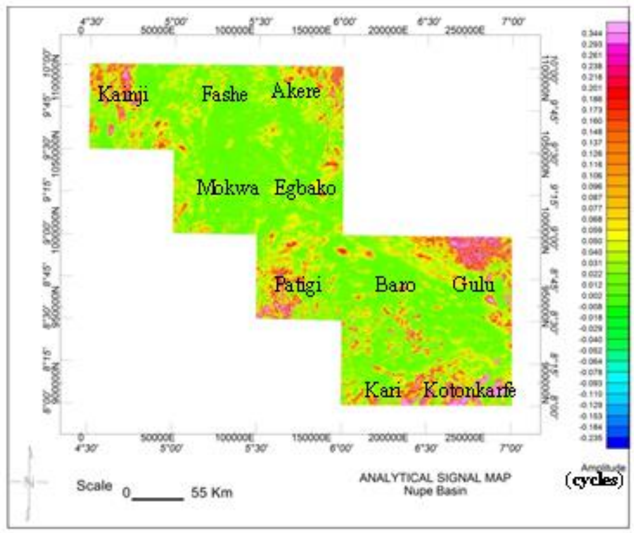

Figure 6: Analytic Signal Map of Mid-Niger Basin

Summary and Conclusion
The IGRF corrected aeromagnetic data of some areas within the Mid-Niger Basin of Nigeria was acquired from the Geological Survey Agency of Nigeria and analysed using the Oasis montaj Software from Geosoft, South Africa for the purpose of mapping line-like regions of discontinuity and lineaments as well as amplitude domain analysis for the delineation of shallow and deeper depths to magnetic sources within the Mid-Niger Basin.
The total magnetic field intensity data was first reduced to pole to show how the anomalies would have been if the data was collected at the magnetic pole. The Centre for Exploration Targeting (CET) phase symmetry grid analysis and analytic signal methods were then applied to the data to reveal the line-like regions of discontinuity and depths within the study area. The CET phase symmetry map (Figure 4) clearly revealed the low amplitude regions associated with deeper magnetic sources as indicated in blue colour and the relatively high amplitude areas shown in pink colour, which are associated with shallow magnetic sources. The

application of this plug-in resulted in the delineation of a NW to SE trend of deep magnetic sources which is clearly discerned on the map with succinct demarcations between the shallow and deeper geological formations.

The result of the amplitude domain analytic signal has revealed areas with high amplitudes, ranging from 0.344 to 0.218 cycles which might be due to outcrops of magnetic rocks while moderate depths are represented in red colour and range from 0.218 to 0.096 cycles. These are areas of shallow depths which could be attributed to intrusions of magnetic basement into the sedimentary basin. The regions with the lowest amplitudes connoting deeper regions which arise due to intrusion of magnetic basement into the sedimentary basin at greater depths were also delineated indicating a NW-SE direction trend.

REFERENCES

Adeleye, D. R. (1973). Origin of ironstones, an example from the middle Niger Basin, Nigeria. *Journal of Sedimentary Petrology* 43, 709–727.

Adeleye, D. R. (1974). Sedimentology of the fluvial Bida Sandstones (Cretaceous) Nigeria. *Sedimentary Geology*, 12, 1-24. http://dx.doi.org/ 10.1016/0037-0738(74)90013-X.

Adeleye, D. R. (1989). The Geology of the middle Niger basin. In: Kogbe, C.A. (Ed.), Geology of Nigeria, second ed. Elizabethan Publishing Co., Lagos, 335–338.

Akande, S.O., Ojo, O.J., Erdtmann, B.D. and Hetenyi, M. (2005). Paleoenvironments, organic petrology and Rock-Eval studies on source rock facies of the Lower Maastrichtian Patti Formation, southern Mid-Niger Basin, Nigeria. *Journal of African Earth Sciences,* 41, 394–406.

MacLeod, I. N., Jones, K. and Dai, T. F. (1993). 3-D analytic signal in the interpretation of total magnetic field data at low magnetic latitudes. *Exploration Geophysics*, 24(4), 679.

Megwara, J. U. and Udensi, E. E. (2014). Structural Analysis Using Aeromagnetic Data: Case Study of Parts of Southern Mid-Niger Basin, Nigeria and the Surrounding Basement Rocks. *Earth Science Research,* 3 (2), 27- 42

Nabighian, M. N. (1972). The analytic signal of two dimensional bodies with polygonal cross section: Its properties and use for automated anomaly interpretation. Geophysics, 37, 507–517.

Obaje N. G. (2009). Geology and Mineral Resources of Nigeria, Lecture Notes in Earth Sciences. Springer Dordrecht Heidelberg, London New York. 221p.

Obaje, N. G., Balogu,D. O., Idris-Nda, A., Goro, I. A., Ibrahim, S. I., Musa, M. K. Dantata, S. H., Yusuf I., Mamud-Dadi, N. and Kolo I. A (2013). Preliminary Integrated Hydrocarbon Prospectivity Evaluation of the Mid-Niger Basin in North Central Nigeria. *Petroleum Technology Development Journal*, 3 (2), 36-65.

Obi, D. A., Ilozobhie A. J. and Abua J. U. (2015). Interpretation of aeromagnetic data over the Mid-Niger Basin, North Central, Nigeria. *Advances in Applied Science Research*. 6(3), 50-63.

Ofor, N. P., Adam, K. D. and Udensi, E. E. (2014). Spectral Analysis of the Residual Magnetic Anomalies Over Pategi and Egbako Area of the Middle Niger Basin. *Nigeria. Journal of Natural Sciences Research*, 4(9), 44-50.

Ojo, S. B. (1990). Origin of a major magnetic anomaly in the Middle Niger Basin, Nigeria. *Tectonophysics, 85*, 153-162. dx.doi.org/10.1016/0040-1951(90)90410-A

Ojo, S. B. and Ajakaiye, D. E. (1989). Preliminary interpretation of gravity measurements in the middle Niger Basin area, Nigeria. In: Kogbe, C.A. (Ed.), Geology of Nigeria, second ed. Elizabethan Publishing Co., Lagos, 347–358p.

Olaniyan, O., Abbah, U., Nwonye, N., Alichi, A. and Udensi, E.E. (2012). Interpretation of Total Magnetic Intensity Field over Mid-Niger Basin. Nigerian Geological Survey Agency. *Occasional Paper* No. 15. 98p.

Udensi, E. E. and Osazuwa, I. B. (2004). Spectra determination of depths to magnetic rocks under the Nupe basin, Nigeria. Nigeria Association of Petroleum Explorationists (NAPE) Bulletin 17, 22–27.

Udensi, E.E. (2001). Interpretation of the total magnetic field over the Nupe basin in West Central Nigeria using aeromagnetic data. Ph.D thesis Dept of Physics ABU, Zaria, Nigeria.